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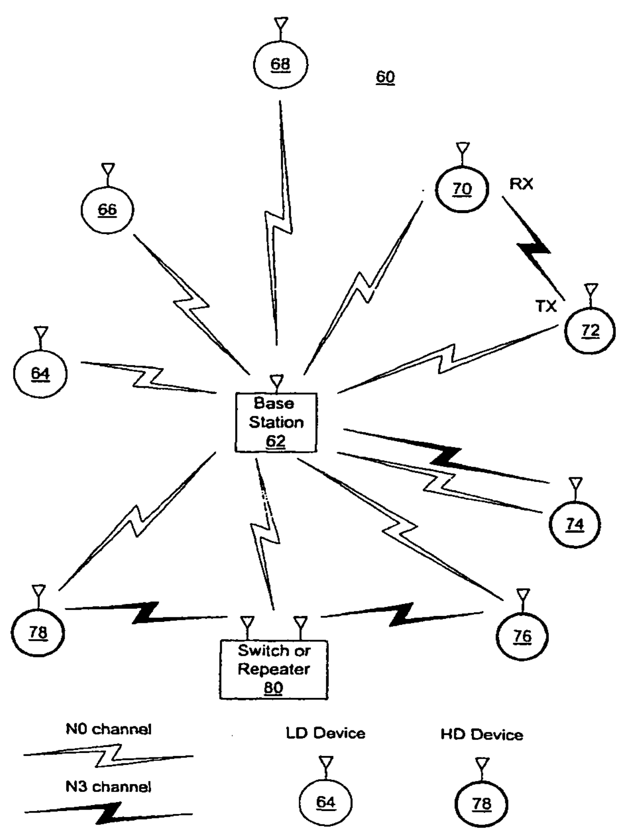
(54) Title: HIGH-SPEED WIRELESS NETWORK WITH A RELIABLE WIRELESS LOW BIT-RATE CHANNEL



(57) Abstract: A multichannel wireless network (60), methods for its operation, and system components are disclosed. The network is designed to facilitate high-bit-rate data communication within a home, office, or similarly constrained area. According to the described embodiments, at least two different types of wireless channels form the network infrastructure. A primary wireless channel is designed for relatively low bit rate, high reliability and network-wide communication. A secondary wireless channel is designed for relatively high bit rate communication, but with potentially lower reliability and shorter ranges. A base station (62) uses the primary wireless channel to configure and control operation of the wireless network (60), including configuring pairs of devices as requested for direct communication over the secondary wireless channel.

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HIGH-SPEED WIRELESS NETWORK WITH A RELIABLE WIRELESS LOW BIT-RATE CHANNEL

FIELD OF THE INVENTION

This invention pertains generally to local area networks. and more particularly to methods and apparatus for implementing a wireless local area network.

BACKGROUND OF THE INVENTION

The flow of a wide variety of electronic information within the boundaries of a home or office has become a reality in today's society. What began perhaps with a simple voice telephone line connection to the outside world has expanded to include cable television. digital television. telephone modems. satellite links. cable modems. ISDN (Integrated Services Digital Network) connections. DSL (Digital Subscriber Line) connections. local area networks. sophisticated security systems. intercom systems. multi-speaker "surround sound" entertainment, smart appliances and smart "houses". etc. New technology will almost certainly expand the future uses for information distribution within the confines of a house or office.

With enough foresight. a new home or office can be equipped with what may be literally miles of wiring, to allow flexible configuration of a home or office to receive and distribute several (or perhaps all) of these forms of information. But once the walls are in place. adding wiring for a new technology, repairing wiring already in place. or even moving existing equipment to a new desired equipment location with no "outlet", may be reduced to choosing between either expensive remodeling or unsightly wiring running along baseboards and window sills. Furthermore. because most of these technologies require their own particular wiring and signaling requirements. a variety of wall sockets and wiring are required. all adding to the expense of construction and detracting from the aesthetics of the space.

Other problems with wired networks exist. For example, merging of multiple differing networks for centralized control, etc., requires expensive bridging, or bridges may not be available at all.

To combat these problems, wireless networks are now being designed for home use. Many of these networks work in the Industrial, Scientific, and Medical (ISM) band that exists at 2.400 – 2.4835 GHz. A second possible ISM band exists at 5.725 – 5.850 GHz. These bands allow unlicensed operation, as they are "garbage" bands that are generally unsuitable for commercial broadcast use (microwave ovens, for example, operate in the 2.4 GHz band). Although low-power, narrowband signals may be jammed by the noise occurring in these bands, digital spread spectrum techniques can be used to effect useful bandwidth.

The Federal Communication Commission has recently created an Unlicensed National Information Infrastructure (U-NII) to further address the needs for wireless digital data communications, particularly for wireless transmission at a rate that can support multimedia. U-NII released three 100 MHz bands for use: 5.15 – 5.25 GHz, for indoor use only and at low power, suitable for short ranges such as within a room; 5.25 – 5.35 GHz, at an intermediate power for mid-range uses; and 5.725 – 5.825 GHz (overlapping the 5.7 GHz ISM band), at a higher power for use up to several miles. U-NII power requirements are designed to encourage wideband uses over narrowband uses, by specifying an allowable transmit power formula that reduces maximum output power logarithmically as signal bandwidth is reduced.

Within the ISM and U-NII bandwidth constraints, several network concepts have been designed, most notably the IEEE 802.11 format, the Bluetooth™ format, and the Shared Wireless Access Protocol (SWAP) developed by the HomeRF Working Group. Each of these formats is designed for use in the 2.4 GHz ISM band. IEEE 802.11 format allows for data rates of 1 million bits per second (Mbps), 2 Mbps, and 11 Mbps, uses either Frequency

Hopped Spread Spectrum (FHSS) or Direct Sequence Spread Spectrum (DSSS) to overcome noise, and has an operational range of about 40 m. SWAP allows for data rates of 1 or 2 Mbps, uses FHSS, and has an operational range of about 50 m. Bluetooth™ format allows for a 1 Mbps data rate, uses FHSS, and allows for several operational ranges, depending on the power "class" of the transceiver; the main applications for Bluetooth™, however, envision the lowest power class transceiver, which has about a 10 m range.

In the IEEE 802.11 format, two operational modes are possible. Distributed coordination Function (DCF) mode implements an "ad-hoc" network structure. In DCF mode, each transceiver uses Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA), i.e., it listens for quiet on the channel before it transmits. Figure 1 illustrates an CSMA/CA "ad-hoc" network formed with transceivers 20, 22, 24, and 26. Each transceiver can communicate with each other transceiver that is within its range, whenever the channel is not already in use. Problems can arise when two transceivers that are out of each other's range (e.g., 20 and 26 in Figure 1) cannot detect each other's transmissions, and attempt to communicate simultaneously using the channel. This system also functions poorly with time-critical information, such as multimedia or voice.

The second IEEE 802.11 operational mode is Point Coordination Function (PCF) mode. In PCF mode, one of the nodes serves as a central Access Point (AP). The AP polls other nodes, asking each if it has data to transmit. Each node only transmits when permitted by the AP. This mode is generally used when the nodes also connect to a wired infrastructure. PCF mode is typically inefficient and poorly-suited to the transmission of time-critical information.

SWAP is similar to IEEE 802.11 in many respects. SWAP also provides two access models, a Time Division Multiple Access (TDMA) service for time-critical data, and a CSMA/CA service for asynchronous data delivery. SWAP can work as an ad-hoc network as

shown in Figure 1. When time-critical services are in use, however, a Connection Point is required. The Connection Point coordinates the TDMA service such that sufficient bandwidth is reserved for the time-critical services. This system's TDMA mode overcomes some of the problems of IEEE 802.11, although bandwidth is more limited.

Figure 2 illustrates the more structured wireless concept employed by Bluetooth™, as described in the Bluetooth Specification Version 1.0B, Nov. 29, 1999. The Bluetooth™ unit of network service is termed a *piconet*, e.g., 46, 48, 50, each of which comprises one master transceiver (28, 34, 40, respectively) and up to seven slave transceivers. Within each piconet, a FHSS channel and phase is established by the master, unique to that master. TDMA is used with 625 microsecond timeslots, with the master communicating in even-numbered time slots. In odd-numbered time-slots, the slave last addressed by the master is allowed to communicate. Each time-slot, the frequency for the piconet is hopped to the next in the hopping sequence established by the master. Slave transceivers follow the hop sequence for that piconet, communicating with the master when allowed by the master.

A *scatternet* 52 is a group of piconets with overlapping coverage areas. Because each piconet operates on a different FHSS channel, frequency conflicts are infrequent. When conflicts do occur, each piconet may lose a single packet. Although a single transceiver is allowed to be a master in one piconet and a slave in another (e.g., transceiver 34), or a slave in two piconets (e.g., transceiver 38), effective dual-piconet operation can be difficult to establish and maintain, since the specification establishes that overlapping piconets shall not be time- or frequency-synchronized. Furthermore, although a transceiver may have visibility in two piconets, this does not establish visibility between other transceivers in the overlapped piconets. Each connection in each piconet allows only for communication between that piconet's master and one of its slaves.

This structured design has advantages and disadvantages over the other formats described. It provides rigid control that is useful for time-critical applications and "plug and play" operation, and allows for devices to exist in multiple piconets. Lower power requirements decrease interference between overlapping piconets, allowing each piconet to enjoy most of its potential 1 Mbps throughput. But range is limited to less than typical household dimensions, bandwidth is inadequate for multimedia, the structure forces communication only with the master (slaves cannot communicate with each other during their time slots), the number of active devices in a piconet is severely limited, and the structure can waste bandwidth because the master must use an entire time slot each time it gives permission for transmission.

SUMMARY OF THE INVENTION

It is recognized herein that many of the drawbacks of the prior art wireless networking concepts occur because of the diversity of communication needs that these systems attempt to meet with a single shared channel. Some data streams require real-time delivery and/or high bandwidths, and thus tax the resources of the channel. Other data streams may require relatively low bandwidth and can tolerate reasonable delay, but may require strong security and a highly reliable channel. Designing a system that can meet these needs with a single shared wireless channel typically results in operational inefficiency and increased cost for network devices that do not require high bandwidth.

In the present invention, at least two types of wireless channels can exist within a wireless network. A primary wireless channel is used for overall control of the network (and preferably, low data-rate data communication)—this channel need not support a particularly high data rate, but generally should be reliable, secure, and have relatively high interference immunity. Secondary wireless channels can also exist within the network. Each secondary

channel is preferably used for high data-rate communications, generally between a pair of network devices.

This multiple channel approach can achieve several advantages over prior art network designs. For example, network control can be administered from a single point (i.e., a base station or master device). Devices that do not need to communicate at high data rates can be designed to use the relatively low data-rate primary channel only, and can thus be built simply and cheaply. On the other hand, a device that needs to communicate at high data rates can be dynamically allotted a dedicated subchannel tailored to those needs. Although a multitude of secondary wireless links can be simultaneously active, control of these links is administered through the primary wireless channel and can thus be centrally administered with high reliability. And because separate secondary wireless channels can be activated for specific wireless links, each such channel can be individually tailored to provide the needed data rate at a power and modulation that minimizes interference with other active channels.

In one aspect of the invention, a method for operating a wireless base station in a wireless local area network is disclosed. This method comprises establishing at least one primary wireless channel between the base station and each other device on the local area network. The base station uses the primary wireless channel to configure two of the devices on the local area network for data communication over a secondary wireless channel. The secondary wireless channel has a higher data rate than the primary wireless channel.

In a related aspect of the invention, a method for operating a wireless network device is also disclosed. This method comprises communicating over a primary wireless channel with a wireless base station. The method further comprises responding to commands issued over the primary wireless channel by the base station, including a command to configure the network device for communication over a secondary wireless channel with another wireless network device.

In another aspect of the invention, a wireless base station is disclosed. The base station comprises a data modulator/demodulator capable of communicating digital data with other wireless network devices over a primary wireless channel. The base station also comprises a primary wireless channel control manager. This manager issues control messages to other wireless network devices via the data modulator/demodulator and the primary wireless channel. The base station further comprises a secondary wireless channel manager to allocate usage of a secondary wireless channel among the wireless network devices. The secondary wireless channel manager also communicates with other wireless network devices via the data modulator/demodulator and the primary wireless channel.

In yet another aspect of the invention, a wireless network device is disclosed. This device comprises a data modulator/demodulator capable of two-way data communication with a base station over a primary wireless channel. This device further comprises a data modulator capable of transmitting data over a secondary wireless channel having a higher data rate than the primary wireless channel. The device also comprises a channel access control manager coupled to the modulator/demodulator to receive channel control data from the base station. The manager configures the data modulator to operate on the secondary wireless channel in response to channel control data received from the base station.

In a further aspect of the invention, a wireless local area network is disclosed. The local area network comprises at least two wireless network devices, each device capable of two-way data communication using a primary wireless channel. At least one of the devices is also capable of transmitting data over a secondary wireless channel having a higher maximum data rate than the primary wireless channel. At least one of the devices is capable of receiving data over the secondary wireless channel. And one of the devices comprises a base station to communicate with each of the other wireless network devices over the primary

wireless channel. The base station uses the primary wireless channel to control usage of the secondary wireless channel by the other devices.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments described below can be best understood with reference to the drawing, wherein:

Figures 1 and 2 illustrate prior art wireless network concepts;

Figure 3 shows an exemplary deployment of wireless network components in a wireless local area network according to one embodiment of the invention;

Figure 4 shows one protocol stack for a wireless base station operating over a primary wireless channel according to an embodiment of the invention;

Figure 5 shows one protocol stack for a wireless network device operating over both a primary wireless channel and a secondary wireless channel according to an embodiment of the invention;

Figure 6 shows a second protocol stack for a wireless network device;

Figure 7 shows a high-level block diagram for a wireless network device capable of operating according to the invention within the framework of an existing physical wireless standard;

Figure 8 shows secondary wireless channel connections for a partial wireless network employing wireless switches according to the invention; and

Figures 9 and 10 illustrate high-level block diagrams for two wireless switch embodiments according to the invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Throughout the following description, several terms have defined meanings. A *band* is a range of available RF frequencies, although the range need not be contiguous in

frequency. As used herein a *channel* is a communication channel or subchannel that uses RF transmission methods to convey digital information. A channel is not limited to any particular modulation scheme. Two channels can be arranged to be *substantially non-interfering* by arranging them in separate, substantially non-overlapping ranges of frequencies (e.g., two narrowband channels, or two FHSS channels using offset or different pseudorandom hopping sequences or phases), but those of ordinary skill will appreciate that substantial non-interference can be achieved in many other ways, such as by time-division multiplexing, code-division multiplexing (e.g., DSSS), or combinations of several or all of these techniques. A *LD* (low data-rate) device has the capability to communicate only on the primary wireless channel. A *HD* (high data-rate) device has the capability to communicate on both the primary and at least one secondary wireless channel.

The description below focuses on a new wireless local area network infrastructure. It is recognized herein that, among other things, the following properties are desirable in a wireless network for home or small office use:

(1) the ability to serve secure channel devices;

(2) the ability to serve relatively low bit-rate devices;

(3) the ability to serve relatively high bit-rate devices, requiring up to tens of megabits per second and even higher data rates;

(4) the ability to avoid interference sources;

(5) reliable, secure network control, management, and configuration; and

(6) an ability to communicate using various protocols.

The disclosed embodiments can operate within a network offering many, or in some cases all, of these capabilities. When implemented according to the following description, the preferred embodiments can provide an infrastructure backbone supporting a high-data-rate universal radio interface for almost any type of digital data, including the types identified

in the background of the invention. This infrastructure is suitable for household use, office use, and other environments with similarly-limited network extent. Various other advantages of these embodiments will be detailed below.

The networking infrastructure described herein uses multiple types of wireless channels to provide desired network functionality. This includes at least one low bit-rate channel that is designed for high reliability. This channel is used to provide control communications between the various devices served by the network. This channel may also provide a low bit-rate data path for networked devices. At least one high bit-rate channel can also exist within the network. The high bit-rate channel can provide the data transfer capability needed for video, graphics, and high-speed data communications. As compared to the low bit-rate channel, the high bit-rate channel generally achieves high data transfer rates at the expense of range, security, interference immunity, and/or overall reliability.

In order to serve high bit-rate devices, a wireless RF channel operating in a GHz band (such as one of the ISM bands or the low-power U-NII band) is generally required. But signals in these bands fade extremely rapidly due to absorption. Thus it can be difficult to implement a high data rate, highly reliable channel over any appreciable distance in one of the GHz bands. Thus in the examples below, the channel characteristics used for control communications differ from the characteristics of the channel used for high bit-rate data transfer.

The present disclosure presents three related exemplary approaches for providing both high data-rate and high-reliability, long-range wireless communication. In the first approach, a primary, relatively low bit-rate channel is implemented using an RF channel, e.g., in the 900 MHz ISM band (or a similar band), while secondary, relatively high bit-rate channels are implemented using one of the GHz bands. Preferably, primary channel reliability and range are enhanced, e.g., by spread spectrum modulation and/or by incorporating strong error

correction coding into the signaling scheme. In the second approach, a primary, relatively low bit-rate channel and a secondary, relatively high bit-rate channel are both implemented using one of the GHz bands, with at least the primary channel using spread spectrum modulation and/or strong error correction coding. Primary channel and secondary channel transmission can overlap in time, as long as the signals are substantially non-overlapping. For instance, the two channels can use different DSSS spreading codes with a common RF carrier frequency, with the primary channel having a substantially higher chip rate than the secondary channel due to the primary channel's lower bit rate. The third approach is similar to the second, except that the two channels are time-division multiplexed onto the same physical carrier and are logically separated by the receiver. Except where specified below, the operational concepts described below apply to all three approaches.

The relatively low bit-rate wireless channel (also described below as the "N0" channel) acts as a primary network communication channel. The properties that will generally be optimized for the N0 channel include interference immunity, reliability, ease-of-use, and data security. As described above, relatively low RF carrier frequencies, low bit-rate modulation, strong error correction coding, and/or high process gain spectrum spreading can be used to optimize the N0 channel. Additionally, the N0 channel typically employs data encryption and user authentication since computational constraints are low at N0 data rates (e.g., several hundred kbps).

The N0 channel capabilities are imbedded in all network devices, both LD and HD. In LD devices, the N0 channel is used to distribute control information and data. Some examples of LD devices are security devices (e.g., window/door contacts, motion sensors, etc.), some audio devices (e.g., audio players and speakers), and communication devices (e.g., telephones, intercoms).

The relatively high bit-rate wireless channel (also described below as an "N3" channel) acts as a secondary network communication channel. The N3 channel is optimized for streaming information at relatively high data rates from one HD device to another HD device. For instance, an N3 channel will generally use a high RF carrier frequency to allow high data rate transmission. High bit-rate modulation (i.e., high bps/Hz) is also generally preferred, even if this lowers the channel's reliability somewhat. Short physical ranges of operation can also be specified for HD devices, with repeaters and/or switches used to extend range.

An N3 link can be a one-way, peer-to-peer connection between two HD devices. A two-way channel can be created by placing both an N3 transmitter and an N3 receiver at each HD device and configuring a two-way channel between them.

Each HD device also incorporates an N0 link, with N3 links being under the control of the N0 link.

A variety of HD devices may exist within the network. Some examples are television set-top boxes, audio/video servers, computer servers, television receivers, digital video players, gaming consoles, and remote computer terminals. For example, a video player can be configured to transmit on an N3 channel, and a nearby television receiver can be configured to receive on that N3 channel.

Figure 3 depicts an exemplary home or small office network 60 according to an embodiment of the invention. A base station 62 communicates with each of devices 64, 66, 68, 70, 72, 74, 76, 78, and 80, using an N0 channel to control each device's access to the network's channels.

Devices 64, 66, and 68 are LD devices, which communicate only over the N0 channel with the base station. Thus in addition to using N0 for control, any data communication involving an LD device will occur with that device peered to the base station.

Devices 70, 72, 74, 76, 78, and 80 are HD devices, each capable of communicating over at least one N3 channel in addition to the N0 channel. Although such devices may still communicate low bit-rate data over the N0 channel to the base station, each can also transmit and/or receive high bit-rate data over an N3 channel with a peer that is not necessarily the base station.

Figure 3 shows several ways in which the N3 channel(s) can be used. Device 70 is an N3 receiving (RX) node and device 72 is an N3 transmitting (TX) node. Base station 62 has peered devices 70 and 72 in a one-way N3 link from the TX node to the RX node—such an operating mode is useful, e.g., when device 72 supplies video or other graphical content and device 70 displays such content. Base station 62 is also shown itself as a two-way N3 peer to device 74. Although, strictly speaking, the base station need not be capable of N3 operation itself, base station may be, e.g., physically connected to a computer or other device that provides high data-rate services to other devices such as device 74 as illustrated. Also shown are two HD devices 76 and 78 that wish to communicate. This communication is facilitated by having each of the two devices communicate with device 80, which in this instance can be either a wireless repeater or a wireless switch. This configuration is useful, e.g., where devices 76 and 78 are out of direct N3 range of each other, or where devices are constrained from direct communication by network topology.

Establishment of an N3 channel in the network of Figure 3 can proceed as follows. A user first initiates a request for a connection between two devices. For instance, a user's N0-capable menu-driven control device responds to the user's selection of a DVD player's output to a television receiver. The control device's response includes forwarding a request over the N0 channel to the base station. The base station interprets the command, and checks the current status of the DVD player and the television receiver using the N0 channel. If the N3 link associated with either device is busy, the base station can resolve the request by either

terminating the pre-existing connection and establishing the new connection as requested, or by denying the newly-requested service. When the connection is granted, the base station sends an affirmative message to the user's control device; when the connection is denied, the base station sends a negative notification instead. When a connection is granted, the base station uses the N0 channel to program the N3 transmit and receive devices for communication over an N3 channel. The DVD player then transmits video data packets to the television receiver over the N3 channel.

The base station's control of N3 channels can involve various degrees of sophistication. For instance, prior to establishing a link between two N3 nodes, the base station can command the two nodes to send, receive, and report on the receipt of test signals in order to test the wireless channel conditions. This can involve testing and reporting the potential channel's bit-error rate for known test bit sequences, under one or more power settings, frequency bands, modulation schemes, etc. Based on the test report and other information known to the base station (such as the parameters for other N3 channels granted by the base station), the base station selects a set of N3 channel parameters that best fits the needs of the two N3 nodes and the needs of the network as a whole. For example, if a suitable narrowband modulation scheme would require a high-power setting, the base station could opt to institute a lower-power (but higher bandwidth) spread spectrum channel that creates less interference with other N3 channels already granted.

The base station can also monitor the status of each N3 link. For instance, the receiving N3 node can report packet corruption rates or signal loss to the base station over the N0 channel. When a problem is detected, the base station can then attempt to improve the channel. For instance, if interference appears in the allotted frequency band, a new frequency band command can be sent to both the transmitter and the receiver.

Because the base station has a global picture of N3 channel usage, the base station can effectively administer frequency bands, time slots, power settings, and/or spreading codes to be used by each separate N3 link. The coordination of network management in the base station also allows the base station to implement sophisticated network management software without the necessity for similar complexity in other network devices. And since the N0 channel itself is secure, reliable, interference-resistant, and relatively long-range, the basic network does not easily break down.

Figure 4 shows one exemplary communication stack 90 for a base station operating according to an embodiment of the invention. An N0 channel physical layer (PHY) 92 comprises the RF link for the N0 channel, e.g. a spread spectrum modulator/demodulator and RF transceiver operating at a relatively low data rate. N0 channel media access controller (MAC) 94 and logical link controller (LLC) 96 provide link layer services for the N0 channel. N0 channel control manager 98 provides the control functions of the N0 channel. These services include admission of new devices to the network, scheduling usage of the N0 channel by each network device, and delivery of N3 channel control messages between N3 channel manager 100 and HD network devices.

N3 channel manager 100 coordinates usage of the N3 channel by the network devices. Channel manager 100 communicates, via the N0 channel, with N3 channel access control managers located within the HD network devices. Channel manager 100 accepts requests for N3 channel creation, either from higher-layer applications or from other wireless devices, and issues commands to the appropriate network nodes, e.g., as detailed in the preceding description, to control N3 channels. Channel manager 100 also maintains state for the granted N3 channels, and may periodically check the status of each granted channel and update state. Channel manager 100 can dynamically alter the network's N3 channel

configuration to respond to changing conditions, such as interference or changes in overall N3 channel demand.

In addition to the control path provided by managers 98 and 100, a traditional data path is provided, e.g., by IP layer 102 and TCP layer 104. IP layer 102 will typically include a routing capability for routing IP packets from one network device to another over the N0 channel, since in the preferred configuration each network device communicates over the N0 channel only with the base station. In addition, applications 106 residing on the base station can use the TCP/IP path (or other similar paths, not shown) to interact with network devices over the N0 channel.

Figure 5 shows one exemplary communications stack 110 for an HD device operating according to an embodiment of the invention. N0 channel PHY 112, MAC 114, and LLC 116 provide the basic N0 link to the base station. N0 channel control manager 118 provides the higher-level functions that allow the N0 link to be established and controlled from the base station. In addition, manager 118 provides message delivery for N3 channel access control manager 128.

A parallel lower stack section provides an N3 channel PHY 130, MAC 132, and LLC 134. These blocks operate using the N3 channel within the parameters granted by the base station.

Channel management controls 120 enforce the service granted by the base station. Controls 120 accept input from N0 channel control manager 118 and N3 channel access control manager 128, and use these inputs to respectively control the N0 and N3 channels. For instance, controls 120 can modify modulation schemes, frequencies, PN sequences, power settings, and/or transmit timing to agree with the service granted by the base station.

IP layer 122 resides in the N0 stack and in the N3 stack. Preferably, IP layer 122 selects an N3 path for delivery of a data packet over a parallel N0 path when an N3 path exists.

Figure 6 illustrates an alternate stack arrangement that is useful because it allows both N0 and N3 to share access to a physical channel. In this example, the physical channel is an IEEE 802.11-compatible (see background of the invention) channel. Although the 802.11 PHY 142 and 802.11 MAC 144 are compliant 802.11 receivers, they contain additional functionality that allows for logical separation of N0 and N3 transmit channels, with TDM controlled by the base station. Essentially, this functionality selects a first 802.11-compliant transmit bit rate for N0 packets and a second, higher 802.11-compliant transmit bit rate for N3 packets. The network operates in the 802.11 PCF mode. Transmit parameters are selected for each logical channel. Channel management control 160 sets the appropriate parameters for MAC 144 and PHY 142.

802.2 LLC 146 implements an IEEE 802.2-compliant logical link control sublayer. This sublayer recognizes and separates incoming N0/N3 control traffic from data traffic. LLC 146 also interleaves outgoing N0 and N3 traffic as instructed by channel management control 160. The remaining blocks function similarly to their counterparts in Figure 5.

With stack 140 of Figure 6, the potential also exists for 802.11 communication with a wireless device that does not recognize the N0/N3 control layer. Figure 7 shows a high-level block diagram for a network device 170 that can also communicate with a "non-network" (meaning non-N0/N3 network) device. PHY 172 and MAC 174 receive both network and non-network packets over an 802.11 physical link. Network packets are identified by the presence of an N0/N3-specific header; non-network packets have no such header. When a network packet is received, it is passed up to N0/N3 filter 176, which strips and interprets the N0/N3-specific header. If the header indicates that the packet is a network control packet, the

packet is sent to N0/N3 channel control manager 178 for processing. If the header indicates that the packet is a data packet, the packet is passed up to upper layers 180. And when a non-network packet is received, it is passed up to upper layers 180 without further processing.

For outgoing network data and control, N0/N3 filter 176 adds the N0/N3-specific header appropriate for each packet prior to submission to MAC 174. The filter can be implemented in several stack locations, e.g., between MAC and LLC, between LLC and network, between network and transport, or above transport. Implementations at lower stack locations are preferred in order to reduce latency in the control connection.

Any one of several different mechanisms can be used to facilitate communication between network and non-network devices. First, small contention intervals can be included in the base station's TDM plan to allow a contention-based device to access to the physical channel. These contention intervals can be used by non-network devices, as well as by network devices if allowed. Network devices can also be granted (e.g., upon request) time slots to communicate with a non-network device. Preferably, the TDM plan remains flexible enough to accommodate the addition of non-network traffic of variable length.

Turning now to another aspect of the invention, it is recognized that the N0 or primary channel may allow reliable communication over a much larger area than the N3 or secondary channels. N3 device-to-device coverage area may be constrained by transmit power limitations, multi-path delay spreading, blocked paths, and contention. To combat these problems, N3 coverage can be extended using network devices that function as wireless switches.

Figure 8 illustrates a partial network 190 according to an embodiment of the invention, with the base station, LD devices, and N0 links omitted for clarity. Switches 192, 194, 196, and 198 connect via N3 links to form a high-speed backbone network. HD devices

200, 202, 204, 206, and 208 are wireless network "leaf nodes", each connected to one of the switches.

The configuration illustrated in Figure 8 benefits the leaf nodes in several respects. First, each leaf node's effective range for high-bandwidth data communication is extended, while avoiding multi-path and keeping transmit power low. Second, each leaf node can communicate with several different HD nodes concurrently, while maintaining only one N3 link (to the switch assigned to it by the base station). And third, leaf nodes become less location-sensitive, since the switch deployment can provide a relatively uniform coverage for a wide variety of HD device locations.

From a network standpoint, several benefits are also achievable. First, reliability can be improved by providing path diversity. For instance, switches 192 and 194 share a direct N3 link, but if this link goes down, data can still be routed between switches 192 and 194 via switch 196. Second, scalability is improved, since network capacity can generally be increased and connections decreased by the addition of more switches. And third, because the base station still uses the N0 channel to configure the network, N3 physical channel usage can be optimized on a network-wide basis under central control, with no dependency on N3 links necessary to administer the network.

Figure 9 shows a high-level block diagram for one embodiment of a wireless switch 192 according to the invention. Switch 192 comprises air interface circuitry and MAC resources to support a plurality of wireless links. The links can be configured to be substantially non-overlapping by frequency division multiplexing, time-division multiplexing, code-division multiplexing, or by a combination of these techniques. The air interface circuitry comprises a modulator and/or demodulator for each wireless link. The air interface circuitry can also comprise a separate RF transmitter, receiver, or transceiver for each link. In the alternative, multiple air interface circuits can share a common RF circuit.

Switch control is accomplished via N0 channel air interface/MAC circuitry 210. Circuitry 210 allows a base station to communicate with N0 channel control manager 212 and N3 channel access control manager 214, in essentially the same manner as the base station controls other network devices. The primary difference when compared to the preceding description is that N3 channel access control manager configures multiple N3 channels (or subchannels) under base station control. For instance, switch 192 is illustrated with one in/out pair of air interface circuitry (216, 218) configured for communication with a node A; second and third in/out pairs of air interface circuitry (220, 224; 226, 228) configured respectively for communication with a node B and a node C; a fourth incoming air interface circuit 230 configured to receive from node D, and a fourth outgoing air interface circuit 232 configured to transmit to node E.

Packet switch 234 maintains a routing table that allows packets arriving at one incoming air interface to be routed to an outgoing air interface. Routing table updates can be provided by neighboring switches, and/or by the base station over the N0 channel air interface 210. The operation of the switching core itself is well understood by those skilled in the art, and will not be detailed further.

A modified version of packet switch 192 of Figure 9 can be advantageously deployed as a bridge to other types of networks. For instance, Figure 10 illustrates a switch/bridge 240 that provides three two-way network links, a HomeRF interface 242, and a 10/100 wired Ethernet interface 244. Packet switch/bridge 246 allows data to pass in and out of the network via interfaces 242 and 244.

Those of ordinary skill will understand that various aspects of the embodiments described above can be combined in a large number of permutations. Furthermore, many alternate implementations, functionally equivalent to those described herein, will become apparent to those of ordinary skill upon reading this disclosure. Such permutations and

alternate implementations are intended to fall within the scope of the invention as claimed below.

The preceding embodiments are exemplary. Specific standards and protocols mentioned herein illustrate a few possible configurations; the invention is applicable to configurations using alternate, additional, and/or new standards and protocols. Although the specification may refer to "an", "one", "another", or "some" embodiment(s) in several locations, this does not necessarily mean that each such reference is to the same embodiment(s), or that the feature only applies to a single embodiment.

WHAT IS CLAIMED IS:

1. A method for operating a wireless base station in a wireless local area network, the method comprising:

establishing at least one primary wireless channel between the base station and each other device on the local area network; and

using the primary wireless channel as a control channel to configure two of the devices on the local area network for data communication between the two devices over a secondary wireless channel, the secondary wireless channel having a higher data rate than the primary wireless channel.

2. The method of claim 1, further comprising using the primary wireless channel as both a control channel and as a relatively low data-rate, as compared to the data rate of the secondary wireless channel, data channel between the base station and another device on the local area network.

3. The method of claim 2, further comprising forwarding data received on the primary wireless channel from one device on the local area network to another device on the local area network.

4. The method of claim 1, wherein the primary wireless channel and the secondary wireless channel occupy at least partially-overlapping frequency bands, with at least the primary wireless channel using spread spectrum modulation to allow simultaneous use of both channels within the local area network.

5. The method of claim 4, wherein both channels use spread spectrum modulation, further comprising modulating the primary wireless channel with a larger spreading code than the spreading code used for the secondary wireless channel.

6. The method of claim 1, wherein the primary wireless channel and the secondary wireless channel occupy at least partially-overlapping frequency bands, the base station time division multiplexing transmission over the primary and the secondary wireless channels by the network devices.

7. The method of claim 1, further comprising using the primary wireless channel to monitor the status of the other devices on the local area network.

8. The method of claim 1, further comprising admitting devices to the local area network using the primary wireless channel.

9. The method of claim 1, further comprising encrypting data before placing that data on the primary wireless channel.

10. The method of claim 1, further comprising authenticating each transmission received on the primary wireless channel.

11. The method of claim 1, wherein using the primary wireless channel as a control channel to configure two of the devices comprises, when the base station receives a request that requires establishing a secondary wireless channel between two network devices, using the primary wireless channel to check the status of each of the two network devices, and,

when the status will allow the secondary wireless channel to be established, using the primary wireless channel to program the two network devices for direct communication with each other over the secondary wireless channel.

12. The method of claim 1, further comprising issuing a request over the primary wireless channel to a pair of network devices that the two devices test channel conditions for a secondary wireless channel between the two devices.

13. The method of claim 12, further comprising basing a grant of secondary wireless channel bandwidth or power on the results of the channel condition test.

14. The method of claim 1, further comprising monitoring the status of the secondary wireless channel, and instructing the two devices to change the parameters of the secondary wireless channel when the secondary wireless channel becomes unsuitable for the data communication needs of the two devices.

15. The method of claim 1, wherein one of the two network devices is a wireless switch, the base station using the primary wireless channel to set up multiple secondary wireless channels between the wireless switch and other network devices.

16. The method of claim 1, wherein one of the network devices is a wireless repeater that repeats signals received on a secondary wireless channel, the base station using the primary wireless channel to configure the repeating behavior of the repeater.

17. A method for operating a first wireless network device comprising:

communicating over a primary wireless channel with a wireless base station; and

responding to commands issued over the primary wireless channel by the base station to configure the network device for direct communication over a secondary wireless channel with another wireless network device.

18. The method of claim 17, wherein the first wireless device has the capability to communicate packet data over multiple secondary wireless channels, comprising at least one incoming and at least one outgoing channel as configured by the base station, further comprising maintaining a packet data routing table, and switching packet data from an incoming secondary wireless channel to an outgoing secondary wireless channel based on a comparison of destination information contained in each packet to the packet data routing table.

19. A wireless base station comprising:

a data modulator/demodulator capable of receiving digital data from and transmitting digital data to other wireless network devices over a primary wireless channel;

a primary wireless channel control manager to issue control messages to other wireless network devices via the modulator/demodulator and the primary wireless channel; and

a secondary wireless channel manager to allocate usage of a secondary wireless channel among the wireless network devices, the secondary wireless channel manager communicating with other wireless network devices via the modulator/demodulator and the primary wireless channel.

20. The wireless base station of claim 19, wherein the data modulator/demodulator is capable of spread spectrum modulation.

21. The wireless base station of claim 19, wherein the data modulator/demodulator uses error correction coding for communication over the primary wireless channel.

22. A wireless network device comprising:

a data modulator/demodulator capable of two-way data communication with a base station over a primary wireless channel;

a data modulator capable of transmitting data over a secondary wireless channel having a higher data rate than the primary wireless channel;

a channel access control manager coupled to the data modulator to receive channel control data from the base station, the manager configuring the data modulator in response to channel control data received from the base station.

23. The wireless network device of claim 22, wherein the data modulator/demodulator and radio frequency modulator share a common radio frequency transceiver.

24. The wireless base station of claim 22, wherein the data modulator/demodulator is capable of spread spectrum modulation.

25. The wireless network device of claim 22, further comprising a radio frequency demodulator capable of receiving data over the secondary wireless channel, the manager configuring the radio frequency demodulator in response to channel control data received from the base station.

26. A wireless local area network comprising

at least two wireless network devices, each device capable of two-way data communication using a primary wireless channel,

at least one of the wireless network devices capable of transmitting data over a secondary wireless channel having a higher maximum data rate than the primary wireless channel,

at least one of the wireless network devices capable of receiving data over the secondary wireless channel,

one of the wireless network devices comprising a base station to communicate with each of the other wireless network devices over the primary wireless channel, the base station using the primary wireless channel to control usage of the secondary wireless channel by the other devices.

27. The network of claim 26, wherein at least one of the wireless network devices has the capability to communicate only with the base station using the primary wireless channel as both a control channel and as a data channel.

28. The network of claim 26, wherein each communication over the primary wireless channel takes place between the base station and at least one of the other network devices.

29. The network of claim 26, the primary wireless channel comprising multiple subchannels.

30. The network of claim 26, the secondary wireless channel comprising multiple subchannels, wherein the base station has the capability to assign one or more

subchannels to a pair of the network devices for the purpose of direct communication between those devices.

31. The network of claim 26, wherein at least one of the network devices further comprises a wireless switch having the capability to communicate over multiple secondary wireless subchannels including at least one incoming subchannel and at least one outgoing subchannel, the wireless switch capable of routing data wirelessly from a source network device towards a destination network device.

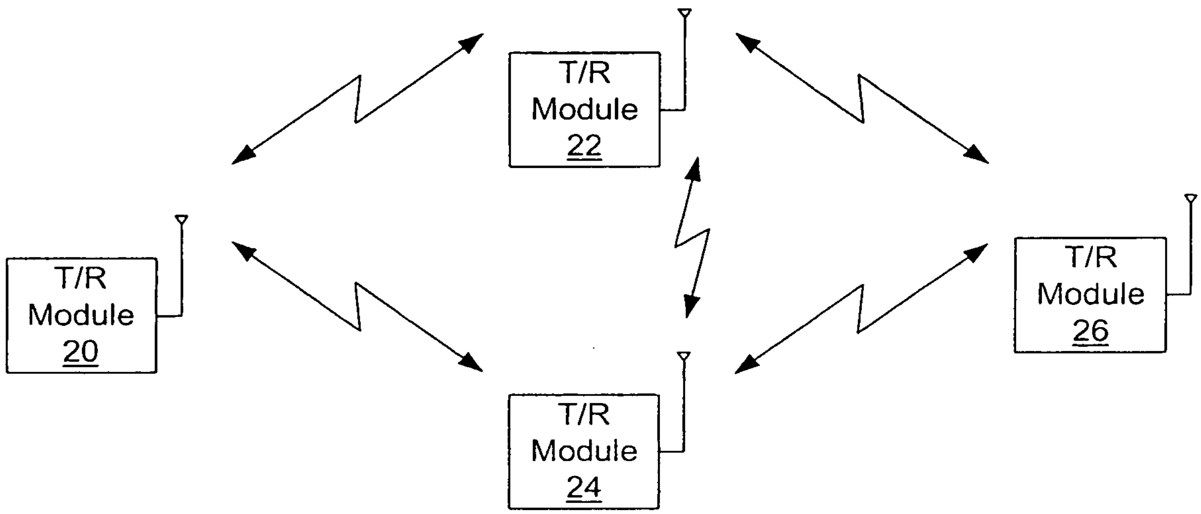


Fig. 1
(Prior Art)

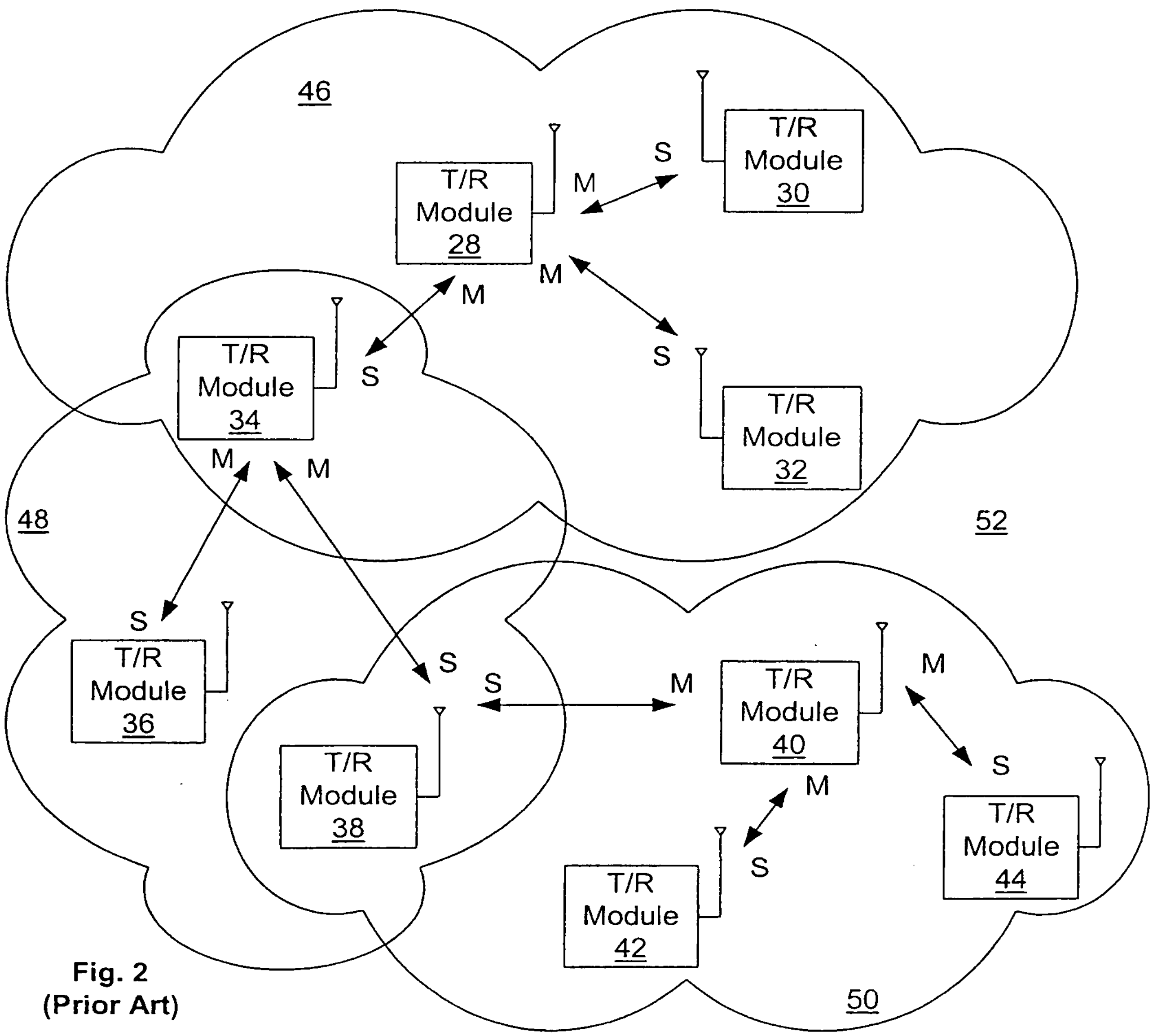
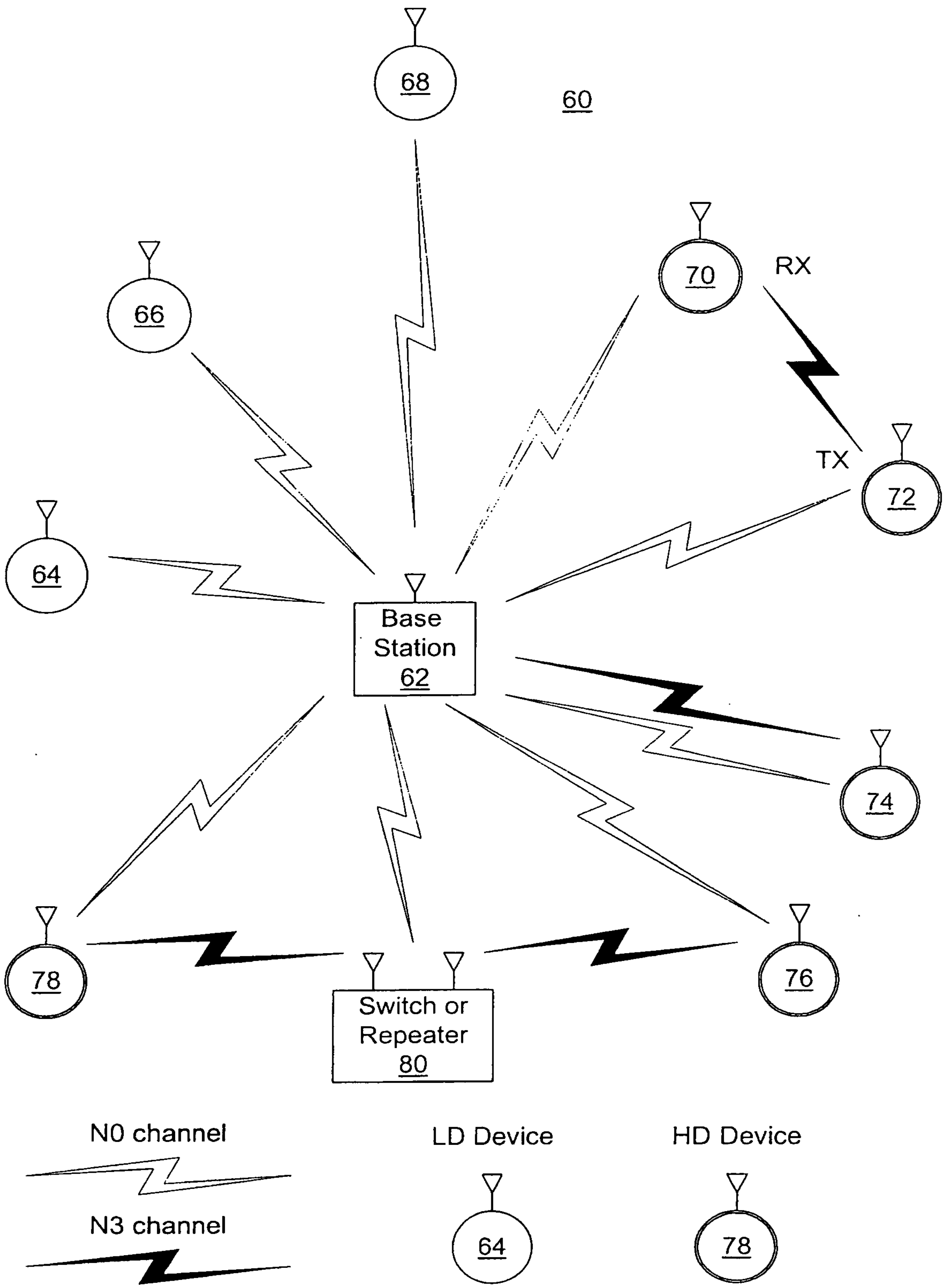


Fig. 2
(Prior Art)

Fig. 3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66
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TX
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Base Station 62
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Switch or Repeater 80
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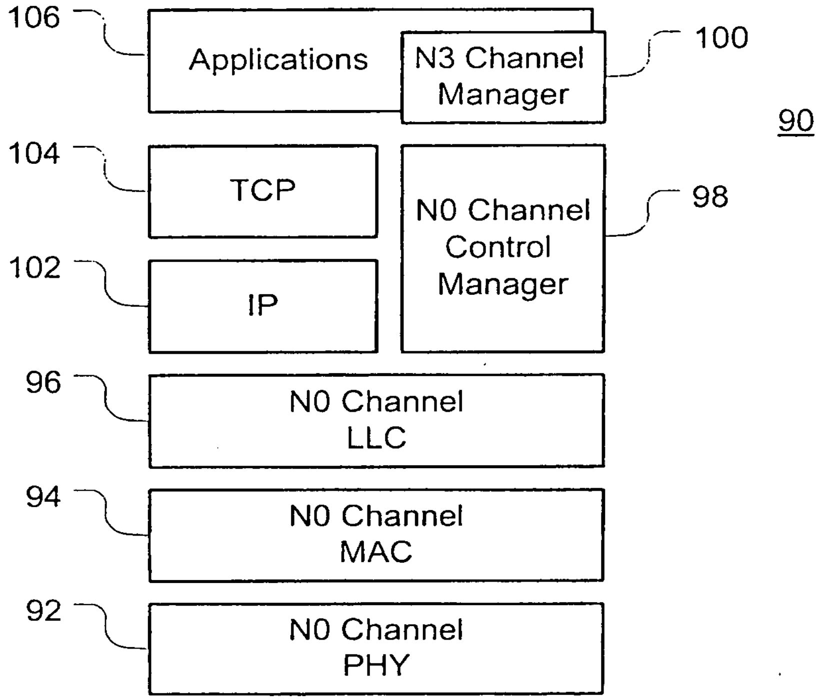
N0 channel
N3 channel
LD Device
64
HD Device
78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Applications
N3 Channel Manager
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N0 Channel Control Manager
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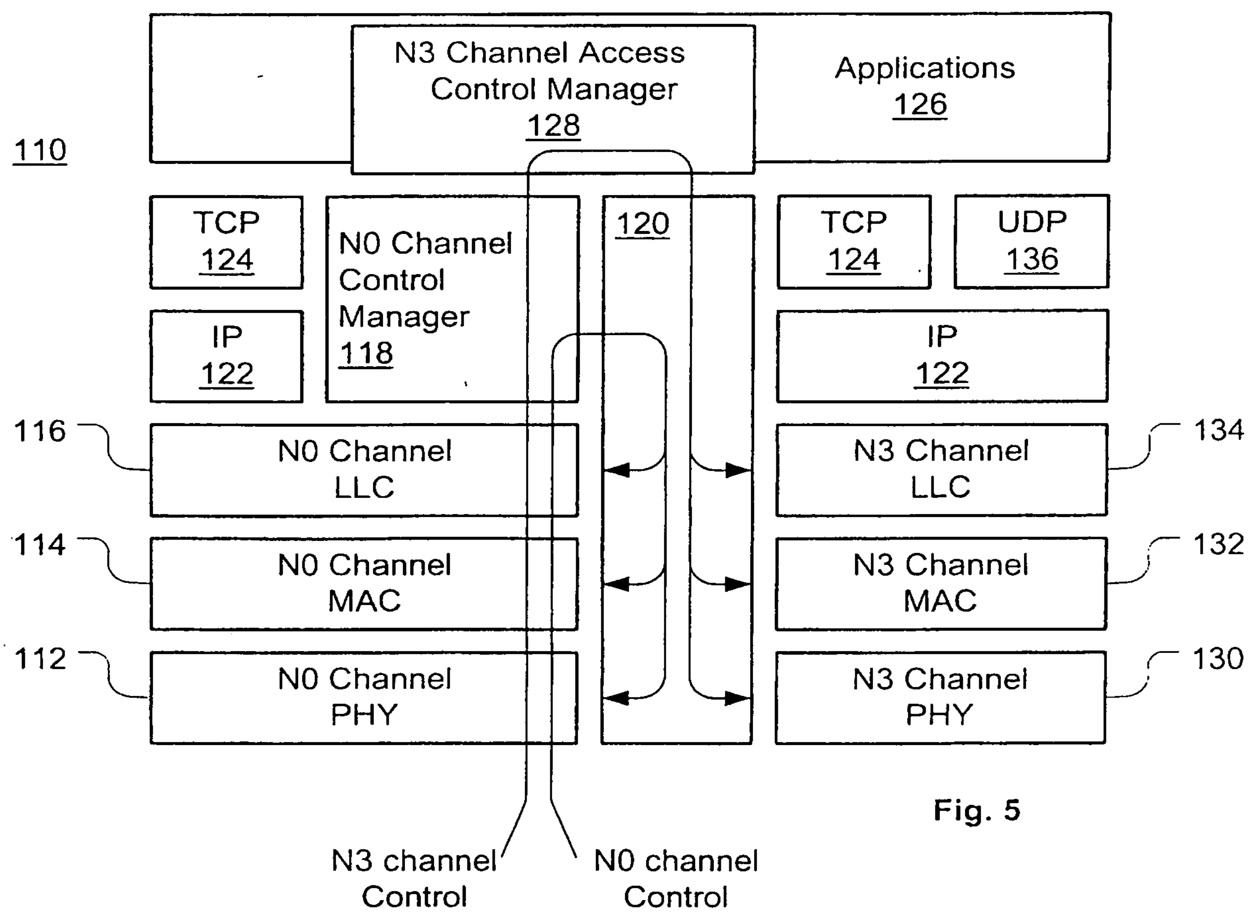
N0 Channel LLC
94
N0 Channel MAC
92
N0 Channel PHY

Fig. 4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N0 Channel Control Manager
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TCP
124
UDP
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IP
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IP
122
116
N0 Channel LLC
N3 Channel LLC
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114
N0 Channel MAC
N3 Channel MAC
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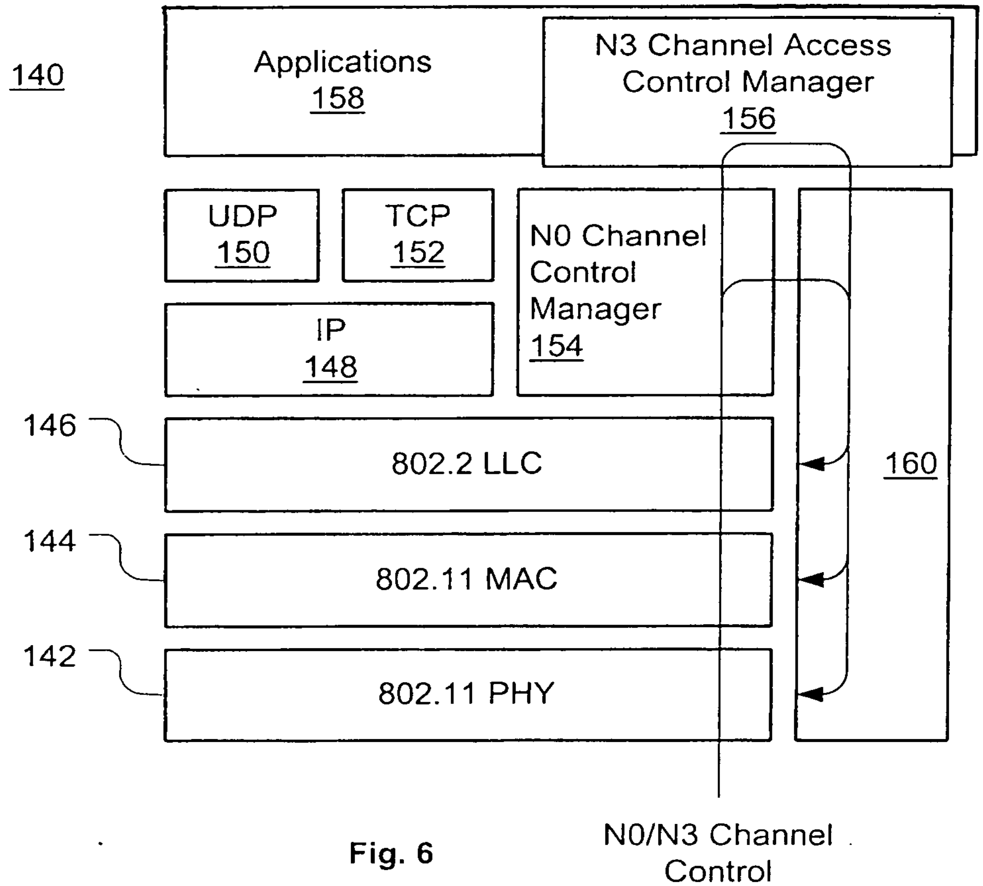
112
N0 Channel PHY
N3 Channel PHY
130
N3 channel Control
N0 channel Control

Fig. 5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UDP
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802.11 PHY
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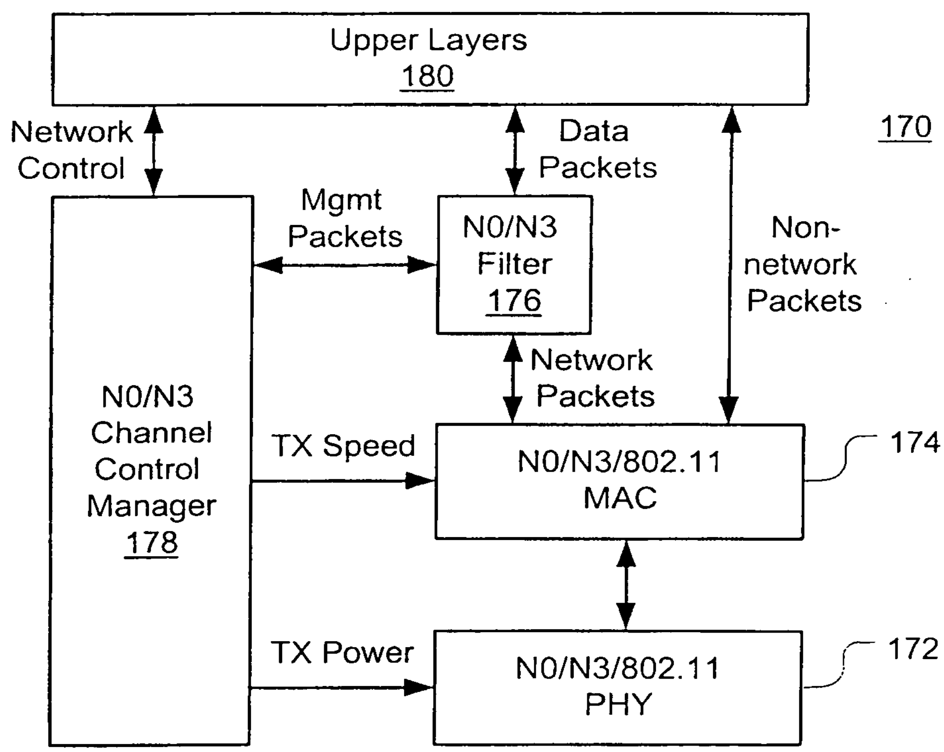
N0/N3 Channel
Control

Fig. 6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Data
Packets
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Mgmt
Packets
N0/N3
Filter
176
Non-
network
Packets
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Packets
N0/N3
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Control
Manager
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TX Speed
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MAC
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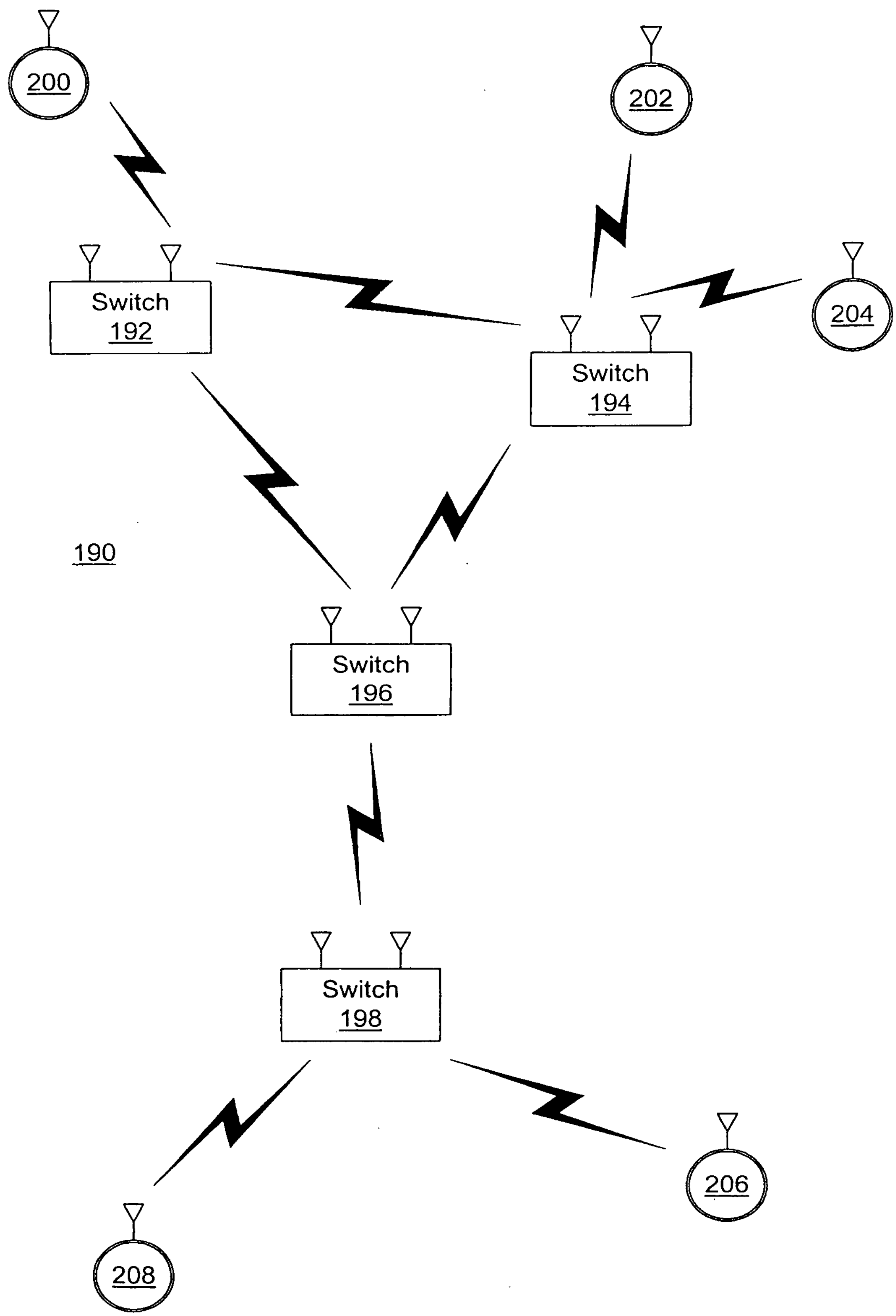
TX Power
N0/N3/802.11
PHY
172

Fig. 7


200
202
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Switch
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Switch
194
190
Switch
196
Switch
198
208
206

Fig. 8

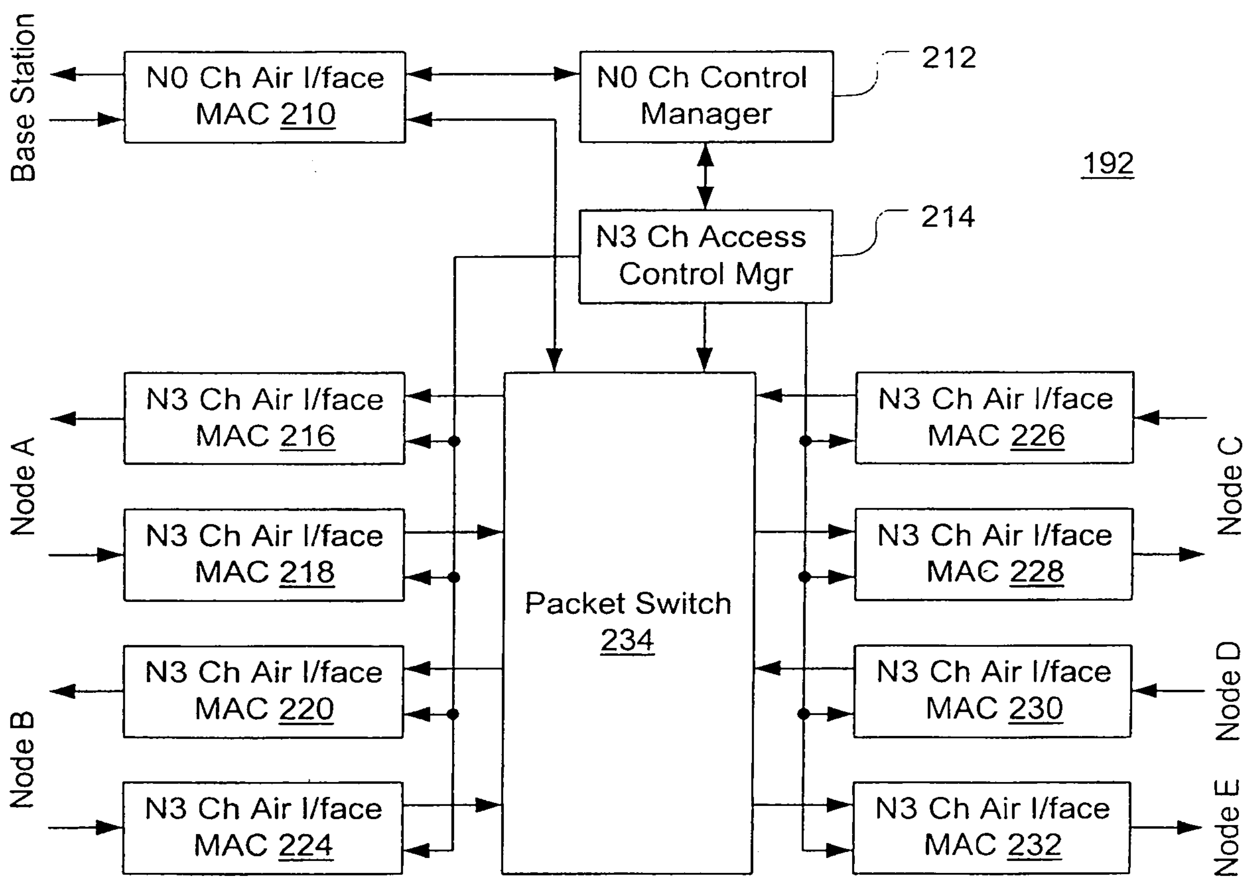
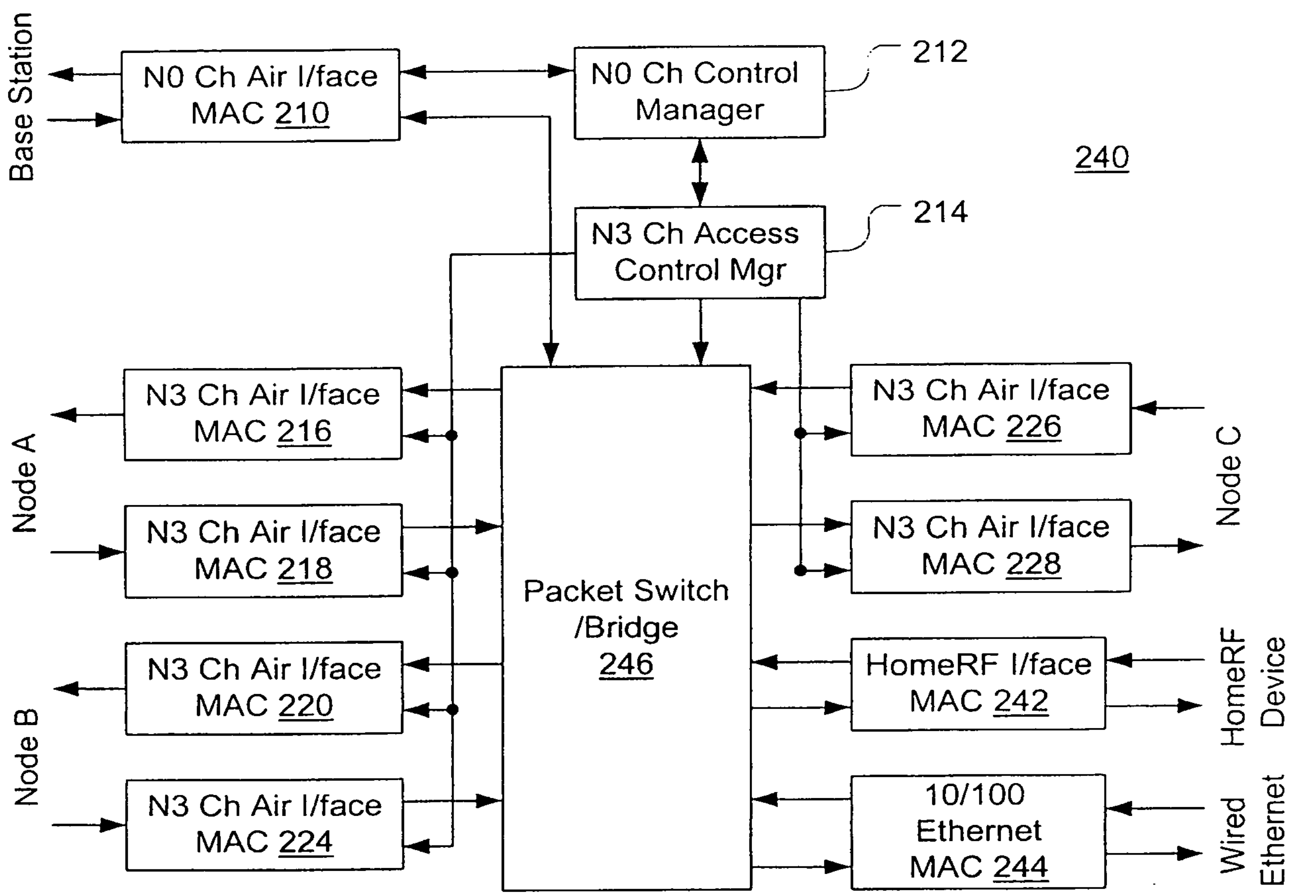

Base Station
N0 Ch Air I/face MAC 210
N0 Ch Control Manager
212
192
N3 Ch Access Control Mgr
214
N3 Ch Air I/face MAC 216
N3 Ch Air I/face MAC 218
N3 Ch Air I/face MAC 220
N3 Ch Air I/face MAC 224
Node A
Node B
Packet Switch 234
N3 Ch Air I/face MAC 226
N3 Ch Air I/face MAC 228
N3 Ch Air I/face MAC 230
N3 Ch Air I/face MAC 232
Node C
Node D
Node E

Fig. 9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N0 Ch Control Manager
212
240
N3 Ch Access Control Mgr
214
N3 Ch Air I/face MAC 216
Node A
N3 Ch Air I/face MAC 218
N3 Ch Air I/face MAC 220
Node B
N3 Ch Air I/face MAC 224
Packet Switch /Bridge 246
N3 Ch Air I/face MAC 226
Node C
N3 Ch Air I/face MAC 228
HomeRF I/face MAC 242
HomeRF Device
10/100 Ethernet MAC 244
Wired Ethernet

Fig. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/21304

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :H04L 12/56
US CL : 370/328, 338
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 370/328, 338

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,068,916 A (HARRISON ET AL) 26 NOVEMBER, 1991, ALL	1-31
A	US 5,644,576 A (BAUCHOT ET AL) 01 JULY, 1997, ALL	1-31

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

- * Special categories of cited documents:
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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search

01 OCTOBER 2000

Date of mailing of the international search report

02 NOV 2000

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